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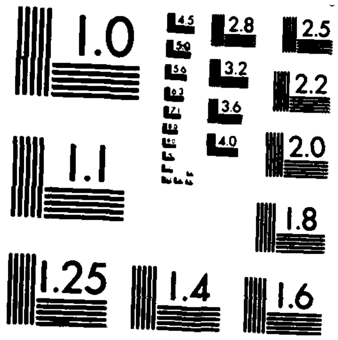


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Initial research and development efforts were made to ~~improve~~ were analyzed methods for 3-D computer graphics reconstruction of damaged brain tissues in living subjects. ~~We sought to analyze~~ some of the clinically more intriguing VHIA tapes in order to establish whether it is feasible with such material to obtain accurate and reliable 3-D reconstructions. Four main issues evolved. 1. The only conclusive check on accuracy of computer graphics modeling is obtainable by making an accurate 3-D reconstruction following death, by reconstructing 3-D images from tissue sections, postmortem. 2. Automatic boundary detection is needed for potentially more accurate, and certainly more reliable, objective and essentially indefatigable detection methods and to provide the ability to reconstruct a sufficient number of cases to establish the database required for comparison between injured and "normal" neuroanatomic structures. 3. Superimposition of model of normal neuroanatomical structures with injured structures was accomplished, though a "warping algortihm" to accommodate 3-D warping is not available at this time. 4. Proper reconstruction of injured brain ___(over)


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structures was not possible for reason of the narrow range of Hounsfiled numbers that depict intracranial structures, using CT Scans of that vintage.

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# 3-D RECONSTRUCTION OF INJURED BRAIN STRUCTURES

*FINAL REPORT*

Robert B. Livingston, M.D.

9 September 1986

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
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findings
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## "3-D Reconstruction of Injured Brain Structures"


Narrative Summary

This grant supported initial research and development efforts to improve methods for 3-D computer graphics reconstruction of damaged brain tissues in living subjects. The project aimed "to produce 3-dimensional images and provide 3-space stereotactic coordinates for any point inside the skull and view the image from any angle, superimpose a tailored model of normal neuroanatomic structures on the image, produce prototype computerized 3-D images, and identify and resolve problems arising in developing software programs using representative CAT Scans of VHIS tapes".

We sought to analyze some of the clinically more intriguing VHIS tapes in order to establish whether it is feasible with such material to obtain accurate and reliable 3-D reconstructions. Scans available were taken at 5 mm intervals using routine clinical procedures in a series of volunteer veterans who had sustained relatively massive penetrating wounds of the head during the Vietnam War. Two-dimensional images were derived from data on VHIS tapes obtained with a 1981-83-vintage technology GE-8800. Reliable 3-D reconstructions from these data would complement traditional methods of 2-D CT-Scan analysis that constitute the most central element of the brain structure/function study program inaugurated by William F. Caveness, M.D. and continued by Andres M. Salazar, M.D., Colonel, MC, USA, and his colleagues.

It was therefore our purpose to discover which parameters of density discrimination would be most likely to yield discernable boundaries between skull and soft tissue (quite easy), between nervous tissue and cerebrospinal fluid and porencephalic channels (relatively more difficult), and between gray and white matter (really infeasible), and among nuclear masses of only slightly differing densities (problemmatical). This leads directly to consideration of the problem of accuracy and reliability of boundary detection among these various structures and in relation to structures involved in wounding and their consequences.


## Accuracy and Reliability of Boundary Detection

Accurate 3-D reconstructions would closely correspond to the actual intracranial contents, enable roughly quantitative interpretation of defects, and provide some evidence relating to the dimensions of the functioning remainder of brain structures.

The only conclusive check on accuracy of computer graphics modeling, of course, is obtainable by making an accurate 3-D reconstruction following death, by constructing 3-D images from tissue sections, postmortem. This is a procedure which the Brain Mapping Project is presently in the process of developing. The remarkable life-history profiles established by the VHIS Project makes the priority for

obtaining autopsies in each of these cases take on extraordinary importance for the analysis of brain structure/function relations. Evidence could be obtained sooner and more easily by comparing CT-Scan data with another form of scanning, e.g., magnetic resonance imaging (MRI). Thus, it will be valuable to compare CT-Scans with MRI scans whenever that becomes feasible. Since the newer technology carries no known risk to the individual scanned, a comparison of past CT-Scans with MRI scans has special virtues for the interpretation of both methods. Even without that, some clues can be obtained simply by comparing successive sections of the same scanning run because neuroanatomy has considerable predictability of structural continuity, even at 5 mm intervals. Reliable 3-D reconstructions, of course, are repeatable using the same data on successive runs.

## The Need for Automatic Boundary Detection

It is desirable to derive the 2-D images automatically (or nearly automatically) not only to avoid an inordinate expenditure of labor by neuroanatomical observers that is otherwise required, but also to avoid individual observer biases and letdown from distractions and fatigue. Automatic boundary detection and 3-D reconstruction is not only potentially more accurate, it is certainly more reliable, objective and essentially indefatigable. Automatic boundary detection is necessary to reconstruct a sufficient number of cases to establish the database required for making comparisons among brain-injured cases and with models of "normal neuroanatomic structures". Furthermore, automatic boundary detection is essential for the exportation of 3-D reconstruction methods to other settings.

Efforts were dedicated to creating 3-dimensional images and providing a suitable strategy for obtaining 3-space stereotactic coordinates for any point inside the skull and views from any angle of the brain and skull images. The differences in density between bone and soft tissues is so cliff-like that boundary detection is not a problem whatsoever. It has been solved by a number of programs in the literature and is available as an adjunct to several commercially available scanning systems. Stacking of skull sections to make three-dimensional objects is likewise no problem. Movement of the head can usually be easily detected and at least partially corrected for.

Some filtering and arithmetic adjustments to boundary detection programs can sharpen the image without notable distortions. Recently Shankar Chatterjee, Assistant Professor of Electrical Engineering and Computer Science at UCSD has developed a boundary detection algorithm that works better than any we have seen in operation and better in principle than any in the literature. This involves a bar-search comparison of contrasts encountered when sweeping the bar around a pixel in the vicinity of the boundary. Thus when the bar is lined up along the boundary to some extent, there will be less contrast over the extent of the bar than when it is lying athwart the boundary. The bar-search can economically examine for contrast and define the boundary in this way as it moves along. Moreover, since it operates on

relative contrast, it can accommodate large degrees of difference in steepness (vividness of staining, for example) along different parts of the boundary. [Nevertheless, when the boundary is washed out by low level noise that is equivalent to boundary definition signals, even the best software is unable to cope.]

## Superimposition of Model of Normal Neuroanatomical Structures

A second major contribution undertaken was to superimpose a tailored model of normal neuroanatomic structures on the VHIS case image. This we did by projecting onto the oscilloscope either the neuroanatomical model or the image in question. The image produced by the Evans and Sutherland Picture System 2 could then maneuver in relation to the projected image and sized to fix approximately, by rotation, translation, and scale. Equivalence of the two images is approximated in this way and dimensions estimated in accordance with identifiable E&S parameters and arbitrary or (if known) actual value scales applied. We do not yet have a "warping algorithm" to accommodate 3-D warping. Dr. Fred Bookstein, one of our long-standing collaborators, at the University of Michigan, says that under his guidance a graduate student working for about six months can solve this problem. Thus far we have not had the resources to apply to that opportunity. For the present, we are deferring 3-D warping in favor of learning more about operating experience with 2-D warping in a wide variety of contexts. Nonetheless, we shall be obliged to face up to the requirement for 3-D as well as 2-D warping. So far as we know, there is no existent algorithm that can be applied in the former case, in this or any other computer graphics applications.

We have attempted to identify and resolve problems arising in development of software programs as applied to representative CAT Scans of VHIS tapes. What is completely refractory, and to out knowledge the only completely refractory problem, is that relating to the paucity of contrast in the raw CT-Scan data with respect to parenchymal tissue.

## Progress and Accomplishments in 3-D Reconstruction

Simply stated, there was little difficulty in creating 3-dimensional images of skulls from which 3-space stereotactic coordinates were derived for localization inside the skull and viewing from any desired angle. The central aim, however, was to develop methods for visualizing and making explicit 3-dimensional images that can distinguish between relatively damaged and relatively undamaged parenchymal tissues. The key problem is the "reconstruction of injured brain (not skull) structures". We found that proper reconstruction of injured brain structures was not possible for reason of the narrow range of Hounsfield numbers that depict intracranial structures, using CT Scans of that vintage. We explored several different approaches in an attempt to extract reasonable parenchymal images, but to little

avail. Repeated analyses on the same scan section gave erratic and unreliable results. Comparison of analyses of successive sections, at least in areas of chief interest, in the vicinity of lesions, was inconsistent. There was a lack of expected continuity of structure.

Each method tried required the operator to exercise prior knowledge of neuroanatomy in order to discriminate boundaries within the tissue regions of greatest interest. This was exactly what we did not want to have to depend on: prior knowledge of what "ought to be structurally reasonable" and "what might be interpreted as being altered" in some spatially definable way. Use of prior knowledge and of subjective criteria did not yield satisfactorily objective 3-dimensional reconstructions for purposes of charting areas of damage that intrude into or displace what remains as residual functional tissue. The distinctions between relatively obviously damaged regions and apparently relatively undamaged regions was not only arbitrary but variable when reprojected from different points of view.

Ambiguities remained whether we used the "region growing" algorithm developed by Dr. Michael Rhodes or software previously developed in this laboratory, by way of exploring different methods for boundary detection.

It would be unreasonable and unjustified to assume an ability on the basis of what we were able to extract from the digital readouts of tapes provided, to distinguish among the possible morphological consequences of wounding and the margins of damaged and/or displaced tissues that might be functional, whether functioning pathologically or "normally".

We asked help of Dr. Michael Rhodes because of his extensive experience in CT-Scan boundary detection and in extracting 2-D data, but he, too, was unable to obtain reliable and presumably accurate boundaries. We asked help of Dr. Pavarti Dev, an experienced boundary detector, principal scientist at Contour Medical. The interpretation of tapes sent to her was not possible in her experience. Similarly, we appealed for help in imaging from Gould and Silicon Graphics with similar disappointment.

There is no problem getting images of inner and outer tables of skull and making impressive 3-D reconstructions of that structure, including bony defects in the VHIS cases. But to distinguish parenchymal boundaries, as we must do in order to make 3-D reconstructions of injured brain structures, defeated us all.

We made some crude overlay superpositioning of 0035 whole brain structures onto 3-D reconstructed skulls, using Evans and Sutherland interactive programs to position the two structures relative to one another, one being projected as an image on the screen while the other is moved about. Yet this did not yield clues that would be a sufficient guide to the uncharted parenchymal neuroanatomy. For example, stereotactic coordinates are of no avail if you cannot establish boundaries of defective and presumably unaffected brain structures. It was even impossible to detect displacement except in crude terms that

are not substantially improved over what is visible two-dimensionally. The PI invested over 125 hours total in painstaking reconstruction using the Contour Medical CEMAX 1000, under the guidance of Mr. William Andrews and with the expert clinical advice of Dr. Dennis K. Bielecki. Again, it was not difficult to obtain reasonably respectable looking skull parts, including defects associated with injury. It was considerably more difficult to reconstruct the cerebral ventricles which, even in the best instances, looked raggedy. Where porencephaly obtained, the imaging of ventricular defects was made problemmatical. Making half-skulls, with brain contents, lesion and all, represented within the cranial vault made impressive pictures which we sent to Dr. Andres Salazar, but there could be no reasonable confidence in boundary discrimination -- it looked rather like bulky amorphous shambles in different shapes. These shapes were only crudely equivalent from one 3-D reconstruction to another using the same original data. This reflects the fact that with Hounsfield numbers so close together the boundary detection algorithm is responding probabilistically and countour are without well defined gradients.

We tried making "ring stacks" of reconstituted objects in order to do "editing" in the form of 3-D sculpting to make the structures "look more reasonable." But this approaches idiocy as far as sensible and useful derivations are concerned.

## Conclusions:

With the 33 cases provided from the *VHISP on GE 8800* tapes, we could not read a few cases and could not read some parts of others, but we did obtain 2-D images for most of them that were equivalent to the usual CT-Scan results. We successfully reconstructed bony parts with respect to all cases that we could read. The only difficulties encountered in some instances were the result of metalic fragments which gave rise to deformations of the beams and consequent deformations of contouring in the vicinity of such fragments. But we never did, in any case, obtain accurate, reliable boundaries that would enable interpretations to be made as to what were the margins of functional tissue. Since that was the principal aim of the project we can testify that skull boundaries and stereotactic coordinates are feasible but that quantitative 3-D definition of the extent of damage and the boundaries of presumably functional neuroanatomy is not obtainable with the narrow range of Hounsfield numbers available with that vintage of CT-Scan. Given this conclusion, there is no way to identify and resolve problems arising in developing software programs relative to CAT Scans of VHIS tapes -- rather, the problem lies, in this context, in hardware.

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